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SUPER-MASSIVE STARS: RADIATIVE TRANSFER

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Abstract. The concept of central super-massive stars ($\mathcal{M} \geq 5\times10^4 M_\odot$, where $\mathcal{M}$ is the mass of the super-massive star) embedded in dense stellar systems was suggested as a possible explanation for high- energy emissions phenomena occurring in active galactic nuclei and quasars (Vilkoviski 1976, Hara 1978), such as X-ray emissions (Bahcall and Ostriker, 1975). SMSs and super-massive black holes are two possibilities to explain the nature of super-massive central objects, and super-massive stars may be an intermediate step towards the formation of super-massive black holes (Rees 1984). Therefore it is important to study such a dense gas-star system in detail. We address here the implementation of radiative transfer in a model which was presented in former work (Amaro-Seoane and Spurzem 2001, Amaro-Seoane et al. 2002). In this sense, we extend here and improve the work done by Langbein et al. (1990) by describing the radiative transfer in super-massive stars using previous work on this subject (Castor 1972).

1 Introduction

The radiation intensity $I_\nu(\theta,\phi)$ is defined as the amount of energy that passes through a surface normal to the direction (θ,ϕ) per unit solid angle (1 steradian) and unit frequency range (1 Hz) in one second. The intensity of the total radiation is given by integrating over all frequencies. The three radiation moments (the moments of order zero, one and two) are defined by:

$$
\begin{aligned}
J = &\quad \int_0^\infty J_\nu d\nu = \int_0^\infty d\nu \frac{1}{2}\int_{-1}^{+1} I_\nu d\mu \\
H = &\quad \int_0^\infty H_\nu d\nu = \int_0^\infty d\nu \frac{1}{2}\int_{-1}^{+1} I_\nu \mu d\mu \qquad (1.1) \\
K = &\quad \int_0^\infty K_\nu d\nu = \int_0^\infty d\nu \frac{1}{2}\int_{-1}^{+1} I_\nu \mu^2 d\mu,
\end{aligned}
$$

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The moment of order zero is related to the density of energy of the field of radiation ($E_{\rm rad} = 4\pi J/c$), the moment of order one to the flux of radiation ($F_{\rm rad} = 4\pi H$) and the moment of order one to the radiation pressure ($p_{\rm rad} = 4\pi K/c$).

The transfer of radiation in a spherically symmetric moving medium is considered taking into account the contributions which are of the order of the flow velocity divided by the velocity of light; we include also the variation from the centre up to the atmosphere of the Eddington factor $f_{\rm Edd} = K/J$, where K and J are the radiation moments; $f_{\rm Edd}$ is obtained from a numerical solution of the equation of radiation transfer in spherical geometry (Yorke 1980). We get the radiation transfer equations by re-writing the frequency-integrated moment equations from Castor (1972) in logarithmic variables in order to study the dense gas-star system at long-term,

$$\frac{1}{c}\frac{\partial J}{\partial t} + \frac{\partial H}{\partial r} + \frac{2H}{r} - \frac{J(3f_{\rm Edd}-1)}{cr}u_g - \frac{J(1+f_{\rm Edd})}{c}\frac{\partial \ln \rho_g}{\partial t} = \kappa_{\rm abs}(B-J) \tag{1.2}$$

$$\frac{1}{c}\frac{\partial H}{\partial t} + \frac{\partial (Jf_{\rm Edd})}{\partial r} + \frac{J(3f_{\rm Edd}-1)}{r} - \frac{2u_g}{cr}H - \frac{2}{c}\frac{\partial \ln \rho_g}{\partial t}H = -\kappa_{\rm ext}\rho_g H \tag{1.3}$$

Where we have substituted $F_{\rm rad} = 5p_g v_g/2$. In the equations $\kappa_{\rm abs}$ and $\kappa_{\rm ext}$ are the absorption and extinction coefficients per unit mass

$$\kappa_{\rm abs} = \frac{\rho_g \Lambda(T)}{B},\ \kappa_{\rm ext} = \rho_g(\kappa_{\rm abs} + \kappa_{\rm scatt}), \tag{1.4}$$

$\Lambda(T)$ is the cooling function, B the Planck function and $\kappa_{\rm scatt}$ the scattering coefficient per unit mass. We have made use of $\partial M_r/\partial r = 4\pi^2\rho$, $f_{\rm Edd} = K/J$, and the Kirchhoff's law, $B_\nu = j_\nu/\kappa_\nu$ (j_ν is the emission coefficient), so that the right-hand terms in Castor (1972) are the corresponding given here.

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